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MEASUREMENTS OF STRATOSPHERIC OZONE AND AEROSOLS ABOVE SPITSBERGEN

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Abstract Stratospheric ozone and aerosol data recorded at Spitsbergen (79°N, 12°E) from 1988 to 1992 are presented. Strong dynamical influences like seasonal variations and annual cycles in the ozone concentrations are described. Polar Stratospheric Clouds were detected above Spitsbergen in January 1989 and 1990, but not in the next two years. Volcanic aerosols, attributed to the Mt. Pinatubo eruption, appeared as early as August 1991 above Spitsbergen and were a constant feature of the lower Arctic stratosphere in winter 1991/92.

Introduction

In summer 1988 two instruments for stratospheric investigations were installed in Ny-Ålesund, Spitsbergen (79°N, 12°E). One is a LIDAR instrument and the other a radiosonde station for ozone soundings with ECC sondes. The LIDAR measures ozone concentration profiles in the altitude range 12 - 40 km, using the DIAL method. Accordingly laser pulses at two different wavelengths are emitted simultaneously into the atmosphere. The first one is selected to be in the absorption range of an ozone band (308 nm, the probing channel) and the other one close, but away from ozone absorption (353 nm, the reference channel). The light of both channels is backscattered by molecules and possibly aerosols into a receiving telescope with photodetectors. While the reference channel records the influence of the atmosphere on the emitted laser light, the probing channel additionally experiences absorption by ozone. The stratospheric background aerosol content influences the DIAL retrieval only very little and is therefore neglected. During winter 1991/92 volcanic aerosols disturbed the ozone evaluation for altitudes below 18 km, ozone DIAL data is only available for higher altitudes. The technique and first measurements with this instrument, which was originally developed by the group of Prof. Walther at Univ. of Munich, were presented by Steinbrecht et al. (1989). The instrument is equipped with a narrow bandwidth laser and a detector with several Fabry-Perot-Etalons, which reduce the bandwidth of the detector. This allows LIDAR measurements not only in the dark, but also during polar day. Stratospheric aerosols can be detected with the reference channel of the ozone LIDAR at 353 nm and an additional laser operating at 532 and 1064 nm, which was recently added to the instrument.

Intensive LIDAR campaigns have been performed since 1988, primarily during wintertime. ECC soundings were used to complement the LIDAR data set for periods with unfavourable weather conditions, as well as to intercompare both methods (Fabian et al., 1992). In fall 1990 the German Arctic research station (the Koldewey Station) became operational at Spitsbergen. Since then ECC soundings are performed once a week, with increased sounding frequencies in winter and spring. Meanwhile further instruments have been and will be installed at Ny-Ålesund, to fully meet the requirements of an operational NDSC station (Network for the Detection of Stratospheric Change).

Ozone observations

The development of stratospheric ozone above a station in the high Arctic is dominated by features due to the strong dynamics. Here we want to describe annual, seasonal, and short time fluctuations observed at Spitsbergen.

The available set of ozone sonde data since 1988 can be used to demonstrate the annual cycle of the ozone layer. For that purpose we have integrated the ECC-sounding profiles reaching more than 25 km altitude, well above the concentration maximum. The ozone column density above the burst point is estimated assuming a constant mixing ratio. The resulting total ozone column densities are displayed in

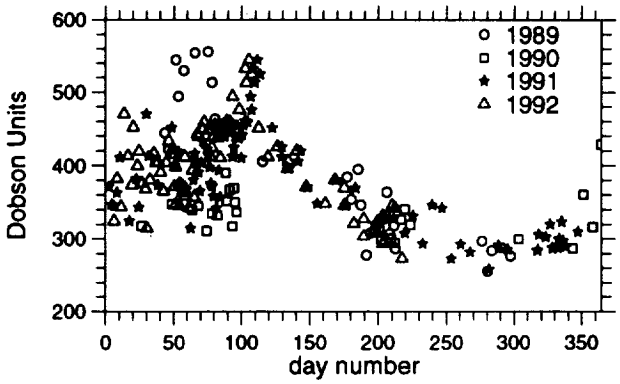

Fig. 1 The annual variation of the total ozone column density, integrated from balloon ozone soundings reaching more than 25 km altitude. Data of the different years is given by the indicated symbols.

fig. 1 in Dobson units (DU). The contribution of the estimate is on the average 32 DU (+/- 15 DU std. dev.). During summer, fall, and early winter we find all available years to show very similar developments. The column density is decreasing from about 400 DU during the summer to 300 DU in early winter. The main feature observed in all the years is the increase of total ozone during the winter with a final maximum just after the break-down of the winter circulation. The only exception is 1990, when ozone soundings stopped at the beginning of April, while the vortex persisted until May. All the other years show maximum column densities around 550 DU, but differ not only in the time when this peak is reached, but also in its duration. While column densities above 460 DU persisted only for about two weeks in 1991 and 1992, total ozone remained high for 45 days after the early vortex break-down in 1989. These annual cycles can be compared with those of other Arctic and sub-Arctic stations, as given by Bojkov (1988). They also experience the springtime maxima, however with a seemingly longer duration. Furthermore Bojkov finds an increase of the amplitude of the annual cycle with latitude. This is extended north with our Spitsbergen data.

The winter months January to March of all years show considerable variations, as displayed in fig. 1. To facilitate comparison of the different years, monthly mean profiles have been calculated from the combined data set of the LIDAR and ECC-sonde soundings (e.g. Neuber and Krüger, 1990). They are given in fig. 2 a) to c). Despite the variations seen for the first 31 days in fig. 1, the January mean profiles of all years agree remarkably well, peaking at 18 km altitude with 5.6 - $6.6 \cdot 10^{12}$ molec./cm^3. The February monthly means differ more strongly in the maximum concentration, which varies from $5.5 \cdot 10^{12}$ molec./cm^3 in 1992 to $7 \cdot 10^{12}$ molec./cm^3 in 1989. The data from February 1989 are split into two sections, because ozone concentrations had increased strongly during the second half of the month due to the early final warming in that year. The highest variations for the three months are found in March (fig. 2 c). This is mainly due to the different timing of the vortex break-down in each year. While the lowest curve for March 1990 gives a profile very similar to that in January 1990,

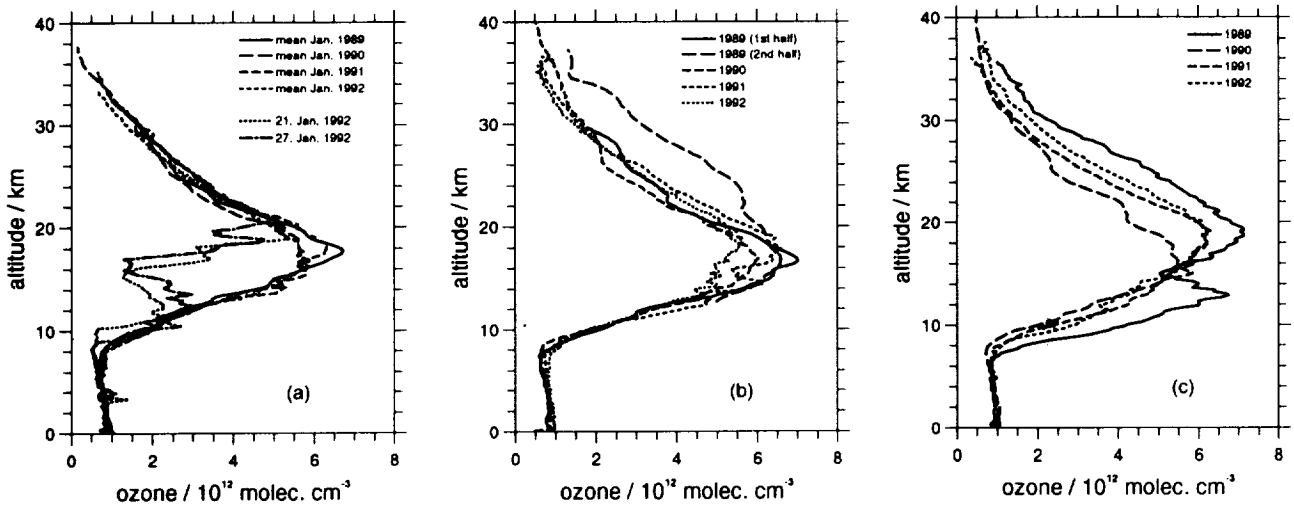

Fig. 2 Monthly mean ozone concentration profiles, calculated from LIDAR and ECC-sonde data for the months January (a), February (b), and March (c). Data of the different years from 1989 to 1992 as indicated. For details of January 1992 and February 1989 data see text.

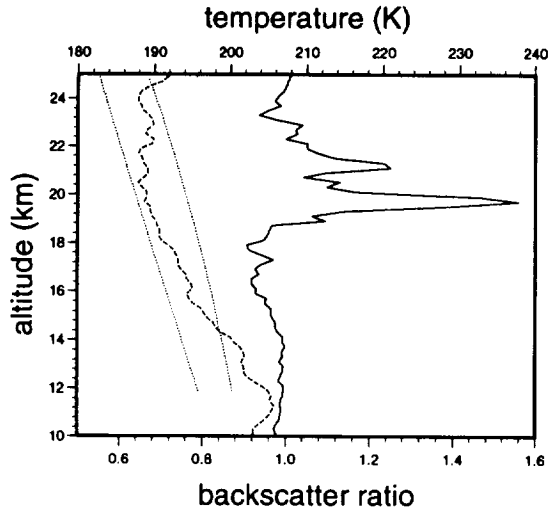

Fig. 3 The backscatter ratio profile, and temperature profile for 15 Jan. 1989, together with profiles of the existence temperatures for PSCs of type I (the right dotted line) and II (the leftmost dotted line. For details see text.

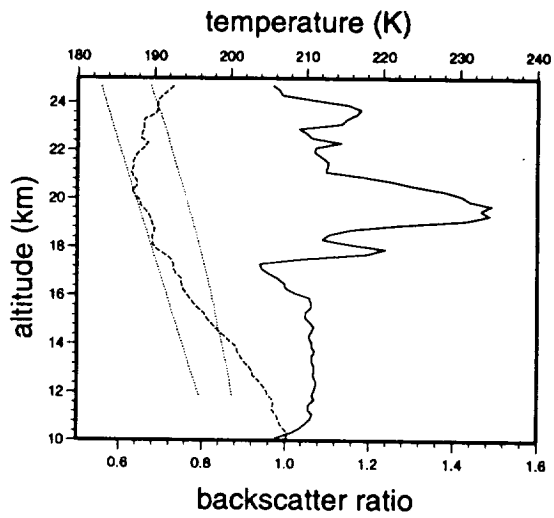

Fig. 4 as fig. 3, but for 27 Jan. 1990.

both obtained while the vortex still existed, the highest ozone concentrations were measured in March 1989, when the vortex had broken down already during February.

In fig. 2 (a) we show in addition to the January mean profiles also two single ECC-ozone soundings, which revealed strong decreases of the ozone concentration between 11 and 20 km altitude. These data are included in the monthly average, which does not show reductions in that altitude regime. Furthermore on the days between 21 and 27 January the ozone concentrations were closer to the monthly mean again. We made a preliminary comparison with ECMWF-trajectories, made available by B. Knudsen from DMI. They reveal that at these days backtrajectories came from significantly different (lower) latitudes, than on the days before and after. Similar reductions were also observed in March 1992, as well as in all the winters before, except during 1990.

It can be stated that the ozone concentrations are modulated by seasonal effects, stratospheric warmings, as well as some reductions during short periods of time. The influence of dynamics might be described by correlating the ozone mixing ratio with potential vorticity, as is done in another paper (Knudsen et al., 1992).

Observations of Polar Stratospheric Clouds

The reference channel (353 nm) of the ozone DIAL, which is not affected by absorption of ozone molecules, can be used to observe the aerosol loading of the stratosphere. Additional scatterers like polar stratospheric clouds (PSC's) significantly enhance the backscattered intensities, from which then backscatter ratios or coefficients can be determined.

The backscatter ratio S is defined as

$$S = (\beta_{mol} + \beta_{aer}) / \beta_{mol}$$

with β_{mol} and β_{aer} the backscatter coefficients of molecular and aerosol scattering, respectively. S equals one for an atmosphere free of aerosols .

In 1989 aerosols were detected between 10 and 17 January and between 23 and 29 January, during the period of coldest stratospheric temperatures. In fig. 3 a profile of the backscatter ratio for 15 January is given, including the actual temperature profile and estimated existence temperatures of PSC's of type I (nitric acid trihydrate, NAT) and type II (water ice). These temperatures where calculated using the NAT data from Hanson and Mauersberger (1988), a typical altitude independent water vapour mixing ratio of 4.6 ppm, and mixing ratios for nitric acid, which vary from 2 ppb at 250 hPa, 10 ppb at 30 hPa to 2.8 ppb at 2 hPa (LIMS data for January at 76°N).

Taking fig. 3 as a typical example of the backscatter ratio profiles observed in January 1989, it shows that aerosols were only detected at altitudes where atmospheric temperatures dropped below the existence temperature of NAT. A LIDAR measurement at 22 January 1989 did not indicate signs of PSC's, although atmospheric temperatures above 18 km were below the NAT existence temperatures. These

observations are in accordance with findings e.g. of Arnold et al. (1992) or Toon et al. (1990), who point out, that the formation of NAT particles strongly depends on the temperature history of the respective air parcel. Consequently, atmospheric temperatures below the existence temperatures for PSCs are a necessary, but not a sufficient condition for their occurrence.

In fig. 4 similar results as in fig. 3 are shown for 27 January 1990. Here atmospheric temperatures even reached the existence temperature of water ice, assuming a water vapour mixing ratio of 4.6 ppm. We find the strongest backscattering ratios exactly in that altitude range, so this might be scattering by water ice crystals.

LIDAR measurements were also performed at Spitsbergen in January 1991 and during the whole winter of 1991/92 as part of EASOE (European Arctic Stratospheric Ozone Experiment). In order to improve the detection of PSCs, an additional laser and detection system has been added to the instrument. It provides pulses at a wavelength of 532 nm with detection in both polarizations. Nevertheless, PSCs were not observed at those times. In Jan. 1990 the atmospheric temperature hardly ever reached the existence temperature for NAT particles. During several short periods in the last winter however, temperatures were low enough at altitudes between 15 and 25 km, without yielding LIDAR signals comparable to those of January 1989 and 1990.

Observation of volcanic aerosols at Spitsbergen

The Mount Pinatubo volcano in the Philippines (15°N, 120°E) erupted in June 1991. Aerosols injected and formed in the lower stratosphere were distributed to high northern latitudes within weeks, as described in several articles in Geophys. Res. Lett. (1992). As early as August 1991, we detected a first sign of this aerosol loading above Spitsbergen between 13 and 15 km altitude. The backscatter ratio of the 353 nm channel showed a maximum of 1.25 in 14 km altitude. The next measurements began with the intensive LIDAR campaign during EASOE, at the end of November 1991. The aerosol signal was found in the altitude range 12 to 20 km during the whole winter. Fig. 5 shows the temporal development of the backscattering ratio for the new 532 nm channel. The altitude of the aerosol peak shows some variations, but generally declines from 16 km in December 1991 to 13 km by the end of January 1992. February and March showed variations in the altitude as well as the magnitude of the aerosol peak. The strongest increase was observed on 20 March 1992, when the final breakdown of the vortex reached Spitsbergen and mid-latitude air with higher aerosol loadings was transported over the arctic polar region.

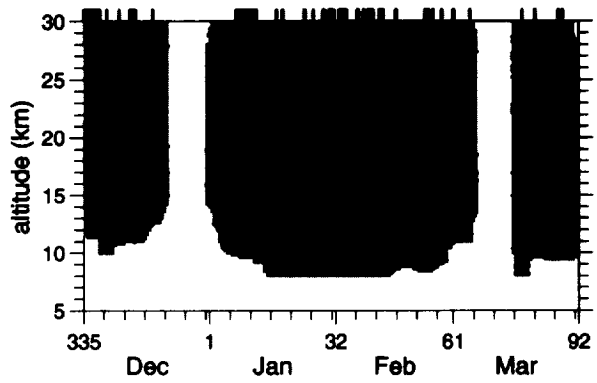

Fig. 5 The development of the backscatter ratio for 532 nm during the EASOE campaign. Data shown was taken from the parallel polarization channel. Vertical bars on top of the plot show measurement times.

Summary

In this contribution we have presented results of stratospheric ozone and aerosol measurements from the Koldewey Station at Spitsbergen for the period 1988 to 1992. Ozone data show high variability due to strong dynamic effects of different scales. Occurrence of PSC's was observed, as well as the Pinatubo aerosols, which appeared over Spitsbergen as early as August 1991. Koldewey Station commends itself for the international Network for the Detection of Stratospheric Change (NDSC) due to its instrumentation and data record and its location with respect to the arctic stratospheric vortex.

Acknowledgements
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